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Robert N. Carrow

Jack Altman

Kenneth Gowans

Paul Harder

Ernst Horber

See next page for additional authors

Authors
Robert N. Carrow, Jack Altman, Kenneth Gowans, Paul Harder, Ernst Horber, Herbert T. Streu, and Carlos Cruz

TURF BULLETIN

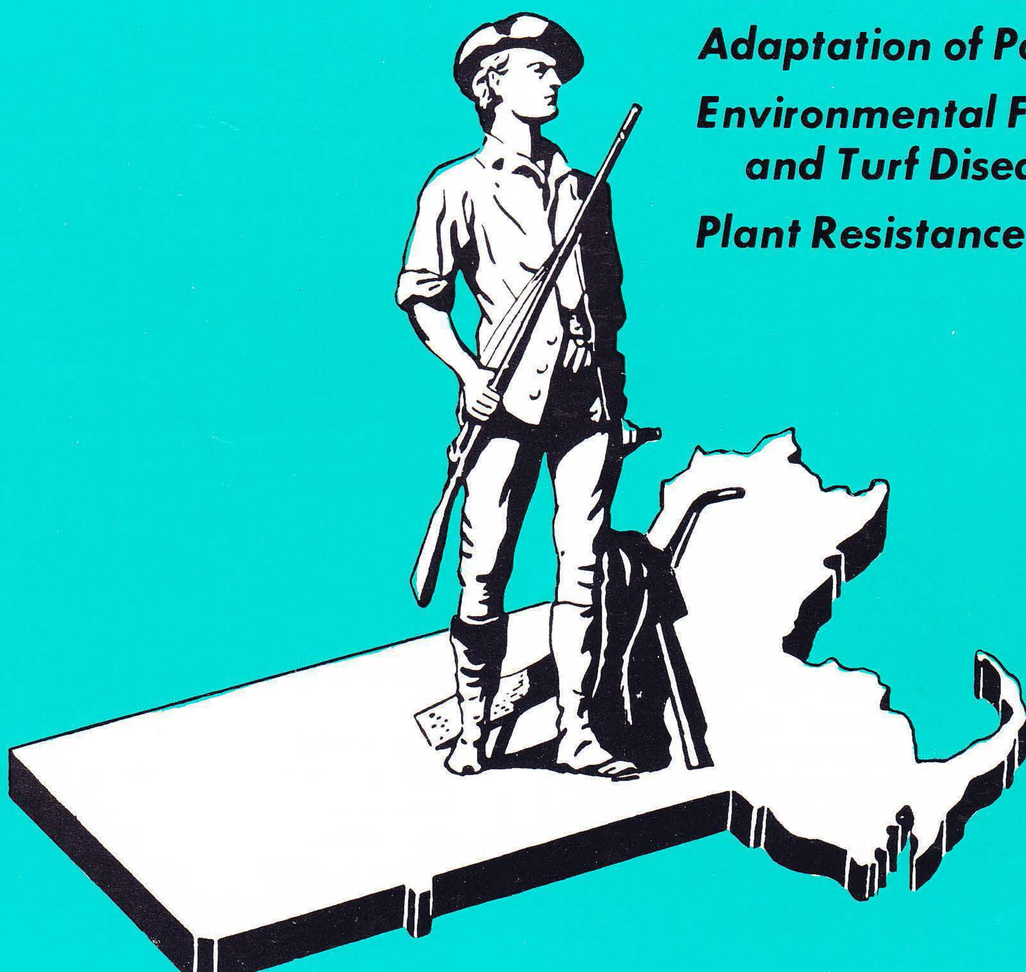
MASSACHUSETTS TURF AND LAWN GRASS COUNCIL INCORPORATED

Featured in this issue:

Adaptation of Poa Annua

Environmental Factors and Turf Diseases

Plant Resistance to Insects



WINTER 1972

BETTER TURF THROUGH RESEARCH AND EDUCATION

EDITOR
Paul R. Harder
Rm. 10 Stockbridge Hall
U.M. Amherst, Mass.

SECRETARY-TREASURER & ADVISOR
Dr. Joseph Troll
RFD No. 2 Hadley, Mass.

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The Massachusetts Turf and Lawn Grass Council Incorporated is chartered under the laws of the Commonwealth of Massachusetts as a non-profit corporation. The turf council seeks to foster "Better turf through research and education."

More detailed information on the subjects discussed here can be found in bulletins and circulars or may be had through correspondence with the editor.

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FACTORS AFFECTING THE ADAPTATION AND COMPETITIVENESS OF POA ANNUA L.

Dr. Robert N. Carrow
University of Massachusetts

One of the major pests on golf courses today is "Poa annua," also called annual bluegrass. "Poa annua" originated in Europe but is now found in all parts of the world. Under irrigated, close cut, high maintenance conditions it forms an adequate turf. However, under stress conditions, particularly high temperature, annual bluegrass is apt to be severely thinned. Also, "Poa annua" can produce seedheads even at very low cutting heights which are unsightly and provide a less desirable putting surface on greens.

Two general approaches to the "Poa annua" problem are: (1) control or eradication, and (2) maintenance as a turfgrass. Control has been attempted by several means: (1) mechanical, (2) competition from more desirable species, (3) biological, and (4) chemical. While complete elimination of "Poa annua" by competition is not generally feasible, a significant level of control can be obtained. Regardless of the control program chosen by a superintendent, competition must be a component if long term success is to be achieved.

The use of competition as a viable control for "Poa annua" requires an understanding of the environmental factors and cultural practices which affect the growth and competitiveness of annual bluegrass. One problem confronting the superintendent is the fairly recent recognition that annual bluegrass is not a uniform species (4, 6, 10). Various ecotypes or strains have evolved in response to different environments and these may not respond to environmental factors and cultural practices in the same manner. Ecotypes may vary from annual to perennial, prolific seed producers to mainly vegetatively-propagated strains, and creeping to bunch ecotypes. The annual strains tend to be bunch-type, prolific seed producers, and to be dominant in unirrigated areas. The perennial ecotypes are more creeping in nature, tend to propagate vegetatively, and to be dominant in irrigated sites.

Another problem is that the relationship between "Poa annua" and the various environmental factors and cultural practices are not as well defined as for bentgrass and other bluegrasses. This situation has evolved because most of the emphasis in research has been on chemical eradication of annual bluegrass. The following is a general discussion of some of the factors which can affect the growth and competitiveness of "Poa annua."

Soil fertility affects the ability of "Poa annua" to persist and thrive at a site. Beard (4, 5) reported that annual bluegrass grew best under fertile conditions. Optimum growth occurred under high nitrogen (0.5 to 1.0 lbs N/1000 sq. ft. per month during the growing season) and high phosphorus. Juska and Hanson (7, 8) found growth best when nitrogen, phosphorus and potassium were added together. Only nitrogen and phosphorus together resulted in increased top growth and reduced root growth.

The competitive ability of "Poa annua" is related to fertility practices (9). Under low fertility annual bluegrass invaded most bentgrass turfs. Only very aggressive bentgrasses resisted encroachment. Acid-forming fertilizers tended to prevent "Poa annua" invasion, while slow-release organic nitrogen sources gave the opposite response.

Soil reaction can influence the growth of annual bluegrass. Juska and Hanson (8), Sprague and Burton (9), and Beard (4) all observed reduced growth of "Poa annua" in the pH range of 4.5 to 5.5. Restricted rooting, low nutrient availability, and nutrient inbalances could account for reduced vigor.

Another factor which may alter the growth and competitiveness of "Poa annua" is soil compaction. Several investigators (1, 4, 10) have reported finding annual bluegrass favored in compacted areas. Youngner (10) noted that "Poa annua" can survive under low oxygen diffusion rates and is, therefore, more competitive relative to other turfgrasses under compacted conditions.

Moisture influences "Poa annua" growth. Youngner (10) observed that under high moisture conditions annual bluegrass was better able to survive compared to dry conditions. Under excessively wet conditions, "Poa annua" was favored over more desirable species. However, prolonged periods of waterlogged soil conditions are detrimental (4). Beard (4) reported that annual bluegrass had a high relative wilting tendency, poor relative drought resistance, and fair relative submersion tolerance compared to other common turfgrasses.

Temperature is a factor which can markedly affect "Poa annua." Beard (2, 3, 4) noted the importance of both low and high temperature stress. Bentgrasses and Kentucky bluegrasses had low temperature tolerances 5° to 10° F below annual bluegrass. Also, "Poa annua" had a reduced tolerance to ice cover compared to other common turfgrasses. The high temperature tolerance of annual bluegrass was well below other turfgrasses. Temperatures of 104° to 105°F were sufficient for kill. Under moisture stress, kill occurred at 100°F. Optimum shoot growth was at 60° to 70°F, while the best root growth occurred at soil temperatures of 50° to 60°F.

Sprague and Burton (9) found that hot, humid weather hastened the death of annual bluegrass, especially if soil conditions were unfavorable. Bartlett and Troll(1) reported that cool night temperatures allowed "Poa annua" to

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withstand warm weather better than if both days and nights were warm. Temperature can also affect the seed germination of annual bluegrass (4, 6). Alternating temperatures of 60° to 75°F were most favorable for germination.

Another environmental factor which can influence "Poa annua" is light. Gibeault (6) noted that light was essential for optimum germination and high light intensity after germination produced maximum growth. Youngner (10) observed that light necessary for seedling development may be a limiting factor for annual bluegrass under higher cutting heights. Seedhead production was found to occur much quicker under full sunlight compared to shaded plants (9). Even though high light intensity appears to be best for "Poa annua" growth, Beard (4) found that annual bluegrass exhibited good shade tolerance.

Associated with the light requirements of "Poa annua" is its response to cutting height. Annual bluegrass is most competitive at cutting heights of 0.7 inch or less. It can persist and produce unsightly seedheads even at 0.25 inch (4, 5).

"Poa annua" is susceptible to several diseases. Bartlett and Troll (1) and Beard (4,5) have reported susceptibility to "Sclerotinia homeocarpa," "Fusarium nivale," "Typhula" spp., "Rhizoctonia solonia," "Pythium" spp., "Fusarium" blight, and "Helminthosporium vagans."

Other factors which can influence the competitiveness of "Poa annua" are smog, wear and insects. Annual bluegrass has poor relative smog tolerance and poor relative wear tolerance (4). The insect "Hyperodes" weevil can cause serious damage in some areas (5).

In summary, "Poa annua" tends to invade areas where conditions are unfavorable for other more desirable species. Excessive nitrogen levels, very low nitrogen levels, overwatering, and compacted soil conditions all favor encroachment of annual bluegrass. Avoidance of these situations will allow the desired turfgrass to be more competitive. In addition to the above cultural practices, the selection of a turfgrass suited to the use and site is mandatory.

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ENVIRONMENTAL FACTORS INFLUENCING TURFGRASS DISEASES

Jack Altman
Department of Botany and Plant Pathology
Colorado State University
Fort Collins, Colorado, 80521

Almost all turf-forming grasses are subject to serious diseases, particularly when maintained under close clipping. A knowledge of the characteristics of these diseases, and of the best methods for their prevention and control is important in successful turf management (Musser, 1950). Environmental factors that produce morbid conditions in growth and development of turf cause disorders referred to as physiogenic diseases. Such diseases are incited by environmental stress and include: extremes in soil moisture content; unfavorable atmospheric and soil microclimate, and chemical or mechanical injuries. Environmental factors that produce physiogenic disease also create conditions that predispose host plants to pathogenic microorganisms. In all instances, an interrelationship exists between the environment, the pathogen, the host and disease development.

Environmental Conditions Favoring Fungus Diseases

Climate and weather have a great influence on disease. Climate determines whether a pathogen can flourish or persist under normal conditions in a given locality. Microclimate determines whether a host-pathogen relationship will develop into disease. All stages in the life cycle of a pathogen take place within fixed temperature ranges.

Temperature appears to be the limiting factor in the behavior of some diseases. Humidity appropriate to the requirements of a pathogen is necessary for all its active stages. Low humidity ordinarily retards or prevents the development of a pathogen. Few plant diseases are damaging under conditions of consistently low humidity. Within limits, an organism's need for moisture varies with the temperature (Nat. Acad. Sci., 1968).

Moisture

The fungi that cause turfgrass diseases need liberal quantities of moisture to germinate spores and sclerotia, and to keep mycelial strands growing actively. The latter are very delicate and cannot withstand drying out. Saturated soils and high air humidity create ideal conditions for their rapid development. Poor drainage, heavy watering and excessive rains that keep soils waterlogged for long periods increase the chances of fungus infection. Humid air and heavy dews keep the foliage wet and also favor fungus growth. Pockets of stagnant air that occur where there is poor air drainage contribute to disease development. In this regard, landscape planning is important (Musser, 1950). Excessive moisture produces lush grass and a more favorable microclimate for disease development. An added factor in waterlogged soil is the inability of the grass to recover from injury because of low nutrient availability and shallow, restricted root-system development.

Soil Moisture

Low soil moisture increases accumulation of toxic ions, such as manganese and boron, causing tissue damage. It can also cause stomatal closure by creating a water stress from the soil system through and including the plant system.

High soil moisture leads to a lack of oxygen in soils. Over long periods, this soil moisture can make plants so succulent they become particularly sensitive to invasion by certain pathogens (Nat. Acad. Sci., 1968). Soil moisture affects both soil-borne and air-borne pathogens. High moisture can lead to root suffocation and injury through reduction in oxygen content. Drying of soil is generally accompanied by reduced pathogen activity, because most fungi go into resting stages as free water disappears from the soil. Temperatures drop further and faster in a dry soil during the winter; therefore, winter kill is prevalent in dry winters.

Temperature

Excessive moisture alone will not cause fungus attacks. It must be accompanied by temperatures that are favorable for development of the disease-producing organisms. Like other plants, each fungus has an optimum temperature for growth. The brown patch organism, "Rhizoctonia," grows best at the relatively high temperatures of midsummer. Snow mold, "Fusarium nivale," represents the other extreme. It causes the most severe damage in the late winter and early spring when temperatures are close to the freezing point. Diseases, such as dollar spot and leaf spot, develop over a much wider temperature range than brown patch or snow mold, but they are apt to be more severe during cool, wet periods in the late spring and early fall.

Soil Temperature

Temperature affects the rate of moisture absorption. High soil temperature can induce disorders such as basal lesions, soil-cracking and root damage. The freezing of soil can directly kill the roots of many tropical and subtropical plants. Persistent and unseasonably low soil temperatures usually stunt plants. Soil temperature may affect disease either by its effect on the host or on the soil-borne pathogen. Cold soils affect mobility of nutrient elements and may cause temporary chlorosis. Therefore, soil temperature is closely connected with abiotic diseases.

Soil Texture

Soil structure can also affect disease development. Turf grown in heavy, compact and poorly-drained soils usually shows greater losses from "Pythium" and "Fusarium" than does turf grown in well-drained soil (Altman, 1966). Soil type may influence amounts of CO_2 in the soil, a change in the balance of microorganisms, lack of available nutrients or other factors.

Light

The diurnal light rhythm affects the periodicity of spore release, partly because of its direct effect and partly because of changes in temperature, humidity and air movement that accompany changes in light intensity at dawn and dusk.

The shade microenvironment is also very important in disease development. Shade adversely alters the turf-grass microenvironment.

It is the more favorable microenvironment of shaded conditions plus the lack of disease resistance that results in the severe disease problem. The microenvironment of shade which encourages disease activity includes: (1) Higher relative humidity; (2) extended dew periods; (3) reduced light intensities that produce a more succulent growth, and (4) low light intensities resulting in lowered respiration rates and, consequently, lower energy levels in the host which restricts cell wall development and maturation. Thus, thinner cuticles and underdeveloped cell walls are produced. The juvenescent state of the host is prolonged and physical mechanical barriers to pathogen penetration are reduced.

Low light intensities do not affect stomatal opening. It seems reasonable to assume that 1,000 ft candles (10% of full sunlight) would be sufficient to open stomates since Zelitch (1961) has shown that only 250 ft candles of light intensity will achieve maximum stomatal opening in tobacco. Therefore, the shade microenvironment that affects the host, such as lower sugar transport under low light intensities, thinner cuticles and a more intense hydrosphere above and around the stomata, are more relevant in the disease syndrome than stomatal opening. "Helminthosporium vagans" is favored by low light intensities. Lukens (1968) refers to this pathogen as the low sugar disease pathogen since it is more severe when sugar levels in the host are curtailed.

Soil pH

No single characteristic of soil is more significant than its pH. Acidity is one reason for the thatching of turf, although not the sole cause (Musser, 1950). Grasses renew a large part of their root system each year. When soils are not too acid, the old roots slough off and decay due to indigenous soil bacteria and fungi. Such decay tends to reduce thatch.

However, in acid soils the dead roots, stems and leaves accumulate forming a thatch, due to lack of microbial activity. This thatch impedes the penetration of air and water and is largely responsible for the formation of localized dry spots in turf. It also creates an excellent medium for pathogenic fungi. "Helminthosporium" thrives on dead organic matter (Altman, 1965).

The pH affects the number of earthworms, bacteria and fungi present in the soil. While fungi develop over a wide pH range, they are most prevalent under acid conditions (pH 4-5). Many of them are desirable and necessary because they are responsible for the initial decay of organic matter, but certain groups are disease-producing. The dollar spot fungus and brown patch fungus, for example, are stimulated by excessive acidity and are checked when acidity is controlled by proper liming in certain areas of the country.

Microbial competitors that keep the disease-producing fungi in check are more active when soil reaction is near neutral. Soil reactions below pH 6.0 tend to favor turf disease fungi. It is often practicable to reduce the severity of disease outbreaks in such turf by light dressings of hydrated lime every 3 or 4 weeks during the time when disease is likely to occur. This practice is safe when soil reaction stays below pH 7.0, but will cause iron chlorosis and trace-element deficiencies when the reaction is pH 7.5 and above. Lime should not be used in the semi-arid sections.

Thatch

A heavy mat of spongy turf provides ideal conditions for the growth of disease-producing organisms. It always contains large amounts of dead leaves and stems which absorb moisture readily and remain damp for long periods. This condition is favorable for the growth of fungi and increases the difficulty of obtaining good control with fungicides. Where turf is heavily thatched, it is often necessary to use excessive water to obtain adequate penetration with a fungicide. Normal fungicide treatments would be too dilute to be effective. To achieve effective disease control, heavier rates of chemicals are required, but these may discolor the turf.

Winter Injury

The most important types of winter injury to turf are desiccation (dehydration) and freezing-out. Desiccation is common in regions where there is limited rainfall and soil moisture is low during the winter months. It is aggravated by dry, cold winds. The dry soil and dry air draw so much moisture out of the dormant or semi-dormant grass plants that they shrivel and die. Injury of this type occurs on both greens and fairways and is most severe on knolls and other exposed areas that are blown free of snow. The damaged grass first has a dull-brown color which may bleach to grayish-white by spring. The best method of avoiding winter injury by desiccation is to moisten the soil thoroughly to a depth of 5 to 6 inches late in the fall and again in winter if rain or snow fall are scarce. It is common practice in northern dry areas to place tree branches and brush on windswept greens to collect and hold snow during the winter.

In Colorado, particularly on the eastern slope of the Rockies, many golf courses are open for winter play. In addition to winter watering of greens, the use of various acrylic turf colorants is increasing. These colorants are composed of polyvinyl acrylics containing a green dye. Treated greens are less prone to desiccation and disease. Less snow mold occurred on 50 greens in continuous play

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during 1967 and 1968 that had been treated with turf colorant and fungicide as compared to greens treated only with fungicide. Greens treated with the combination were less brittle and had better ball retention qualities than non-treated greens. Non-treated aprons were infected with Fusarium snow mold in March and April of each year.

Winter injury of turf due to freezing-out, as distinct from desiccation, is caused primarily by poor surface or sub-surface drainage. It is often aggravated by the use of poorly adapted grasses and by management practices that weaken the turf and make it less tolerant to adverse conditions. Poor surface drainage causes water to collect in depressions. The frozen soil prevents it from draining out, even when its physical condition is satisfactory. Accumulations of snow and ice may produce the same result by damming back the water. The alternate freezing and thawing of such pools causes winter killing of the grass.

A good program of turf maintenance during the growing season often prevents or reduces winter killing. The use of grasses that are cold hardy or adapted to the conditions under which they must be grown is an important factor. For example, when Kentucky bluegrass is destroyed, because of saturated soils on spring seepage or ponded areas, Colonial or creeping bentgrasses should be used. The bents are more tolerant of wet soils and will survive longer under such conditions. The various kinds of bents differ in cold tolerance. Some of the newer vegetative strains, such as Toronto and Old Orchard, are more resistant than other types. Seaside is very susceptible to freezing injury.

Sound fall fertilization will help reduce winter injury provided nitrogen is not applied after mid-September. One pound of nitrogen per 1,000 sq ft will provide a tough grass that is less susceptible to winter damage. Reduced watering also helps to harden the turf and put it in good condition for winter; however, many turf areas will require late fall and winter watering, particularly in arid areas similar to eastern Colorado.

Summer Injury

Turf is subject to many types of injury during the growing season that may be mistaken for disease attacks. These may be due to unfavorable weather and soil conditions or to inadequate maintenance. Scald is a common trouble of this kind. It occurs as irregular areas of discolored turf on poorly drained soils or in depressions on greens during periods of excessive rainfall or when the grass is watered heavily in hot weather. Thorough aeration of the damaged areas to hasten drying and permit air to get down to the roots is a temporary remedy and may save some of the turf. The only permanent remedy is to provide adequate surface and subsurface drainage. The use of lateral stone drains 4-6 in. wide and 12-18 in. deep will help.

Localized dry spots may develop on greens and fairways where the turf suffers from lack of moisture, even when irrigated regularly. This condition may be caused by excessive compaction or because of thatch accumulation. Localized dry spots should be thoroughly aerated and lime and fertilizer added where needed to hasten organic matter decay. They should be watered regularly until normal soil moisture has been restored.

In regions subject to high temperatures and hot, dry winds, turf may be seriously injured because of wilting. This type of injury takes place when the grass roots cannot absorb moisture from the soil as fast as it is lost from the leaves. The first indications are the development of a dull, bluish-green color and severe footprinting on the turf. Wilted turf recovers very slowly, and in serious cases the leaves may shrivel and die. Injury can be avoided by frequent, light sprinkling (syringing) of turf, two to three times daily, to provide readily available moisture to reduce turf and soil temperatures. This type of watering cannot replace normal irrigation to replenish the moisture supply throughout the root zone.

Turf may lose its vigor and thin out because of tree-root competition. This competition can be eliminated by ditching between the putting green and trees that are sources of trouble, or by the periodic use of a deep running singleblade root cutter.

Turf of low vigor, resulting from one or more factors that induce summer injuries, is usually predisposed to red thread and dollar spot. Rhizoctonia brown patch and Pythium grease spot also occur as high temperature diseases in the U.S.

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TURFGRASS SEEDS BY THE POUND

Kenneth Gowans

Turfgrass seed mixtures are labeled in percentage of each kind of grass seed by weight. This can be very misleading if the number of each seed in a pound is not considered. Seed characteristics of some commonly used turfgrasses are listed in the accompanying table. There can be as much as a 40 fold difference in seed count between different seeds. This means that 5 percent of Colonial bent grass in a ryegrass-bentgrass mixture by weight has more bentgrass seeds than ryegrass seeds.

To calculate the number of live seeds in a pound of seed the percent germination and purity is required. Each package of turfgrass seed is required by law to have this information.

TABLE 1. Common Turfgrass Seed Characteristics.

Common Name	Scientific Name	Approximate No. Seeds/lb.	Approximate No. of Days to Germ.
Bentgrass			
Colonial	Agrostis Tenuis	8,500,000	7-14
Creeping	Agrostis palustris (stolonifera)	8,000,000	7-14
Bermudagrass	Cynodon dactylon	1,800,000	14-21
Bluegrass			
Kentucky	Poa pratensis	2,200,000	10-20
Rough	Poa trivialis	2,500,000	10-20
Fescue			
Creeping Red	Festuca rubra	615,000	7-14
Chewing	Festuca rubra (var. or subsp. commutata)	615,000	7-14
Meadow	Festuca elatior	230,000	6-10
Tall	Festuca arundinacae	230,000	7-14
Ryegrass			
Annual (Italian)	Lolium multiflorum	230,000	5-10
Perennial	Lolium perenne	230,000	5-10
Dichondra	Dichondra repens	800,000	7-14

The number of live seeds in a pound is equal to the percent purity divided by 100 times the percent germination divided by 100 times the number of seeds per pound. Or to write this another way:

$$\#LS/lb. = \frac{\%P}{100} \times \frac{\%G}{100} \times S/lb.$$

Where
#LS = number of live seed
P = purity
G = germination
#S = number of seed

Example 1

Seaside creeping bentgrass has a germination of 95%, a purity of 99.5% and from the table we find that there are approximately 8,000,000 bentgrass seeds per pound.

$$\text{No. live seeds/lb.} = \frac{95}{100} \times \frac{99.5}{100} \times 8{,}000{,}000 = 7{,}500{,}000$$

Now let us determine the number of seeds of each grass in a mixture.

Example 2

A mixture of 10% Creeping Red Fescue, 20% Kentucky bluegrass, 68% Perennial ryegrass and 2% crop, weedseed and inert material by weight can be converted to number of seeds and percent by count. The percentage of Creeping Red Fescue seeds remain the same for purity (% by wt.) and by count. There was a reversal in the percentage of Kentucky bluegrass and Perennial Ryegrass. The 20% Kentucky bluegrass seed by weight became 65% by seed count and the 68% Perennial ryegrass by weight became 25% by seed count.

Table 2. Conversion to Number Of Seeds And Percent By Count.

Turfgrass	Purity % by wt.	Germination	No. Seed/lb.	No. Live Seed/lb.	% Live Seed/lb. by Count
Creeping Red Fescue	10% / 100 x	90% /100 x	615,000 =	55,500 = 548,000	10%
Kentucky Bluegrass	20% / 100 x	80% / 100 x	2,200,000 =	355,000 = 548,000	65%
Perennial Ryegrass	68% / 100 x	85% / 100 x	230,000 =	138,000 = 548,000	25%

Seed count is not the only factor to be considered when comparing grass seeds. The number of days to germinate the seed and the aggressiveness of the grass are also important. Ryegrasses germinate the quickest of all grasses and are aggressive, that is, they tiller and fill in rapidly. This means that a seed mixture containing less than 50% of live ryegrass seeds by count can result in a turf containing nearly all ryegrass.

Purity

Purity is an important factor. It refers to the number of seeds of the particular grass. All grass seed may contain some inert material and weed and crop seed. The percentage of these materials are subtracted from the total to obtain the purity.

Germination

Germination or the percentage of seed that will germinate will vary between seed source. The purity and germination can be considerably lower in poor quality than in good quality seed. Therefore, when purchasing seed observe these characteristics of the seed and when comparing price calculate and compare the number of live seeds in each mixture.

Inert Material

This is the percentage of material by weight that will not grow. Poorly cleaned seed may contain a variety of material from the thrashing process. Again, quality seed should contain a very small percent of this material.

Crop

This is the percentage of seed by weight other than those specified that can be grown as a crop. For instance, tall fescue seed may be included as a crop seed in Kentucky bluegrass. If only a few tall fescue plants appear in a Kentucky bluegrass turf you have problems; therefore, it is important that quality turfgrass seed be free of crop.

Weeds

This is the percentage of weed seeds. Again weight of the seeds of different weeds vary considerably, therefore there is no indication of the number of seeds. Unfortunately, some of the problem weeds of turfgrass are not included in the noxious weed lists for most other crops. Again, quality seed should be nearly free of weed seeds.

TOO HEAVY OR TOO LIGHT

by Paul R. Harder

University of Massachusetts

Unless your home lawn is one of a very select few that was constructed on ideal land, you probably have problems with soil that is too heavy or too light. Heavy soils are often poorly drained and poorly aerated which makes it impossible to grow most of the bluegrasses and fescues, the favorites of homeowners. Light soils are often so sandy that extensive irrigating is required in order to maintain a reasonably green lawn. Since water is rapidly becoming a precious commodity, extensive lawn irrigation is not a feasible practice. During renovation or initial lawn construction modifications can be made to improve either situation.

After obtaining the results of your soil texture analysis from your County Extension Service, one of three situations will exist. The topsoil will be perfect for developing a fine lawn or it will be too sandy or heavy (excessive clay). If the topsoil is too sandy, additional organic matter needs to be added to improve the water-holding capacity of the soil. This can be accomplished by mixing peat into the upper 4" to 6" of topsoil. One hundred and seventy-five pounds of peat per 1000 square feet is usually an adequate amount. Additional organic matter can also be incorporated into topsoil by recycling grass clippings and leaves. By shredding leaves and clippings and using them as you would peat moss, the water-holding capacity of the topsoil will be improved while previously worthless material will be put to good use. After either of these amendments are properly mixed, the first step toward a respectable lawn is finished.

If your soil analysis showed a high percentage of silt and clay in the topsoil, then the solution is somewhat different. In order to improve drainage, additional sand has to be mixed with the existing soil. Heavy soils will support bentgrass species more readily than any others and areas that are unavoidably wet will probably be best suited to bentgrasses. Other areas where sand can be mixed to improve the texture of the topsoil sufficiently will support vigorous growth of bluegrasses and fescues. Once the problem of too light or too heavy topsoil has been properly corrected, your chances of developing a healthy lawn are vastly improved. Proper soil texture is the foundation on which every other aspect of turfgrass growth and development ultimately depends. Without a solid foundation more problems will arise than may be financially feasible to correct.

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PLANT RESISTANCE TO INSECTS

by ERNST HORBER

Insect-resistant varieties provide an ideal way to control or suppress insect damage to crops. They involve minimum production costs, leave no insecticide residues in food or the environment, harm no pollinating or otherwise beneficial insects, only minimally disturb nature's balance between destructive insects and their natural enemies and are compatible with biological, chemical, cultural and other control methods. Resistance affects insect pests only while they attack plants.

Plant breeders and entomologists, with relatively small budgets, already have developed some insect-resistant varieties of crops.

Breeding resistant crops is neither simple nor quick. The insect-hostplant relationship requires intricate knowledge of the physiology and behavior of insects, morphology, physiology and genetics of plants. Several genes must be combined and their frequency increased to confer the resistance required in the majority of the plant population. Resistance developed to a pest may not be permanent, or may leave the plant unprotected from another pest. With such easily handled crops as tomatoes or wheat, 8 to 10 years may be required to find resistant germ plasm, incorporate genes into commercially acceptable varieties, and to propagate enough seed for commercial use. In the 1920's it took 15 to 20 years from crossing to release of wheat varieties that resisted the Hessian fly ("Mayetiola destructor" Say); in the 1960's, only 8 years. Moapa, an alfalfa variety that resists the spotted alfalfa aphid ("Therioaphis maculata" Buckton) was developed in only 3 years, an unusual accomplishment.

More recently, efforts have turned to multiple pest resistance. Already some 25 vegetables are reported to fend off 35 species of insects. Many of these successes were achieved with relatively modest research budgets and sometimes little knowledge of the nature of resistance and its inheritance.

After resistance has been developed, "biotypes" or races may then attack the crop. Fortunately, it generally requires several years for such biotypes to develop.

Because of environmental concerns, it is preferable to breed for varietal resistance, even though insecticides considered effective and "safe" are available. A "fireproof building is preferable to "firefighting." Unfortunately because of too much dependence on insecticides, considerable knowledge and germ plasm, involving resistant varieties adapted to local conditions, may have been lost.

Various approaches to hostplant resistance are available. Beck distinguishes two: (1) the "Painter-approach" which entails subjecting large numbers of plants to intense insect infestation, then selectively breeding the survivors. It requires knowledge of the insect's biology and good collaboration with breeder and geneticist. This approach has been combined with the search for resistance in the same or related species or genera to incorporate favorable characteristics into an agronomically desirable variety. That approach has efficiently found resistant varieties to be developed. It still is the most practical, rapid, and cheapest method. (2) Beck's approach, an "after the fact" study, determines the mode of action of resistance, by comparing characteristics of resistant genetic lines with those of susceptible lines. Such studies should follow the first approach to explain the mechanism of resistance and the mode of inheritance. Other approaches involve long-term studies of physical and chemical plant factors and of insect behavior, development, and reproduction on both resistant and susceptible plants.

Insect-Hostplant Relationship

Painter (20) divided insect-resistance, as observed in the field, into three categories: (1) non-preference, rendering the plant unfit or unattractive to insect pests as food, for oviposition, or shelter; (2) antibiosis, adversely affecting growth, survival or reproduction of the pest; and (3) tolerance, imparting ability to withstand, or to recover from injury, despite supporting a pest population that would severely damage susceptible hosts.

Plant resistance is sometimes equated with antibiosis. However, nonpreference should not be overlooked. Where even brief infestations cause severe damage, as when virus transmission occurs or when vital parts of the plant are severed, nonpreference may be more important than antibiosis. Both antibiosis and nonpreference influence the density of insect populations, whereas tolerance exerts no inhibitory effect on insect multiplication. Tolerant plants, supporting larger infestations with little damage or yield loss, may be even more conducive to population buildup than susceptible varieties. Tolerance has value in preventing the buildup of new biotypes and in maintaining natural predators and parasites. In alfalfa, tolerance maintains forage quality, assures stand establishment and therefore helps overwintering of the new crop. However, varietal resistance of the tolerance type must be supplemented by antibiosis, nonpreference, or by cultural, biological, or chemical control.

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The proper balance of the three categories of resistance in the same variety can be achieved and evaluated in pest management programs involving large areas over extended periods.

Phytophagous insects recognize their hostplant through a chain of interdependent conditioned reflexes (3, 16, 32, 35, 58). Visual, olfactorial, gustatorial, and tactile stimuli influence oviposition, feeding, and sheltering and, thus, determine the degree of an insect's host specificity.

Olfactorial and gustatorial chemoreceptors in insects discriminate between acceptable and unacceptable plants (27). High sensitivity of chemoreceptors to inhibitory stimuli or to lack of feeding-incitants is associated with narrow food specialization. In some insects chemotaxis is highly developed, enabling them to detect biochemical changes in plant tissues during different growth stages. Resistance may be conditioned by the presence or absence of the active material in the right tissue at the right growth stage. Biochemicals responsible for resistance may interfere with an insect's physiological processes or may be toxic or repellent (3).

Active materials include attractants, repellents, arrestants, feeding stimulants, and deterrents (3, 6, 7, 32, 58). Before a certain attractant, repellent, or insecticidal property is unequivocably attributed to a biochemical, it should be isolated in pure form and its composition, structure, and activity thoroughly determined in resistant and nonresistant cultivars, preferably isogenic lines. Proved adverse properties of a biochemical to insects should also be evaluated with respect to food value, palatability and toxicity to higher animals.

Choice for feeding, ovipositing, or sheltering may be determined by such external protective features as thickened epidermis, fibrous cuticle or spiny surface, small cavities or crevices, pubescence, or hairiness. They often are difficult to distinguish from chemical factors.

Major emphasis to induce noninherited resistance has been along the lines of crop management; for example, cultivation and proper use of fertilizers. This applies particularly to control of insects that attack long-lived trees or ornamentals. Because of their long lives, it is difficult to develop inheritable resistance. Also, such controls are effective against some important pests that tend to attack only crops that are in moribund or severely weakened condition.

Factors Affecting Expression of Resistance

Some plant varieties have maintained high resistance or near immunity, such as grape to the grape phylloxera ("Phylloxera vitifoliae" Fitch), or apple to the woolly apple aphid ("Eriosoma lanigerum" Hausm.) since the 19th century. However, such stock too often is grown exclusively in an area, or is distributed beyond its ecological range where it encounters aggressive biotypes.

Insect populations often develop new, physiologically distinct biotypes. Polyphagous species are generally less subject to biotype formation than monophagous insects because selection pressure to starvation is rarely achieved. The Hessian fly, spotted alfalfa aphid, greenbug ("Schizaphis graminum" Rond.), and . rubus aphid ("Amphorophora rubi" Kalt.) show that biotypes have a "lock and key" relationship to individual genes for resistance.

Wheat varieties in Kansas and California remain resistant to the Hessian fly. In Indiana, however, extensive acreage of cultivars carrying H_3 gene for resistance caused the fly population to shift from predominantly race A to race B. Now most wheat cultivars grown in Indiana carry resistance to both races (14).

Sources of resistance are available for each of the six races of Hessian fly now known. Other examples of bio-

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types are nine reported in pea aphid ("Acyrthosiphon pisum" Harris) on legumes, four in rubus aphid ("Amphorophora rubi" Katl.) on raspberry, and four in the corn leaf aphid ("Rhopalosiphum maidis" Fitch) on sorghum and corn.

Because most aphids are partly parthenogenetic, a single female, capable of feeding on a resistant plant, may build up a new population.

A new biotype of greenbug, "Biotype C," recently has caused losses to sorghum, but sources of resistance to Biotype C have been secured (12).

Six biotypes of the spotted alfalfa aphid recently were recognized in western United States. Four were identified during a combination of studies including tests on the parental clones of the resistant alfalfa cultivars Moapa and Washoe, involving biological activity and response to some organo-phosphate insecticides.

Fewer cases of aggressive biotypes are known among insects than among diseases. Because resistance to insects is more complex, it is apparently more difficult for an insect to be selected in nature for ability to infest a resistance plant than it is for a pathogen.

The only way to keep ahead of new biotypes is to constantly observe behavior of pests on resistant cultivars and incorporate several genetic factors for each category of resistance—antibiosis, nonpreferance, and tolerance.

Cultivars combining moderate antibiosis with high tolerance may be ideal. They allow an adequate pest population large enough to maintain predators and parasites and to outbreed new or potentially new biotypes, but not large enough to cause measurable crop loss.

The degree to which a plant is suitable as an insect host can be modified by such environmental factors as light, temperature, moisture, and nutrients. Responses of insects, including olfactory and gustatory stimuli, also are modified by environmental changes. Thus, a variety that exhibits resistance in one locality or environment may be susceptible in another.

The optimum temperature for pea aphid reproduction and survival was several degrees higher on alfalfa plants that appeared susceptible under field conditions than on plants that appeared resistant.

The possibility of low temperature reducing resistance was first noted with the spotted alfalfa aphid. Temperature may affect the insect directly or indirectly by influencing growth rate of the insect or its hostplant. Wheat cultivars carrying certain genes for resistance to Hessian fly allow a greater infestation in the greenhouse under high temperatures than under lower temperatures in the field. Temperature differences may explain minor fluctuations in resistance in the field. Effects of high temperature appear to be greater in heterozygous plants.

Soil moisture frequently is influential. Plants attacked by insects with sucking mouthparts appear to be particularly influenced by soil moisture. Either an excess or a deficiency may make the plant more susceptible. Such effects often are superimposed on varietal differences.

Plant nutrition through natural soil fertility or artificial fertilizer affects resistance. Each insect species, and often each hostplant species or variety, constitutes a separate problem.

Plant age may influence resistance, older plants being more resistant.

Breeding Insect-Resistant Cultivars

Selection and breeding for resistance have come a long way since 1878 when farmers noticed differential grasshopper damage in adjacent crops of corn and sorghum. The first was completely stripped, while the latter was almost entirely avoided by these voracious and supposedly omnivorous insects. For most crops, including even forage grasses, "proveniences and landvarieties" have been replaced by "cultivars." The recent development of "isogenic lines," which differ in one single character—for example, resistance to insect or disease—greatly facilitates studies on causes of resistance and their inheritance.

The first step in breeding for resistance is to screen available germ plasm for resistance to a particular pest. Generally, they have been found when adequately researched. Success is generally proportional to the number and diversity of plants available. Efficiency of screening depends largely on successful management of infesting insect population. Techniques are available or may be developed to assess all three categories of resistance and to detect and exploit low as well as high resistance. Adapted lines from the insect-problem area should be considered first because maximum diversity of resistant-related physiology and responsible genes occurs near the center of origin. Frequently resistance to a particular pest is recovered in cultivars or selections from areas where the pest is indigenous. However, natural resistance has occurred in material from areas outside of the natural range of the pest.

Initial screening tests are designed to reject the bulk of the susceptible material. Subsequent screening should exclude escapes and host evasion (20). The remaining few lines are retested intensively to determine consistency of resistance and to discard the pseudo-resistant. Studies on the inheritance of resistance may help to identify different genes for resistance. If naturally occurring variation is not sufficient, genes should also be searched for among other species of related hostplants or in artificially induced mutants.

Close collaboration between entomologists and plant breeders, and frequently plant pathologists and agronomists, is needed.

Information is needed on genetic variance for resistance in both the host and in the insect, and the consequent interactions between such genotypes and the environmental conditions that affect plant resistance and insect aggressiveness. Recurrent phenotypic selection, a form of mass selection, was especially effective in developing resistance to the spotted alfalfa aphid, pea aphid (5), potato leaf-hoppers, alfalfa weevil (2), and European corn borer (9) and for development of multiple-pest resistance (11). Mass selection conserves genetic diversity, increases frequency of desirable genotypes, develops new genotypes, and enhances success of extracting individual plants that combine attributes needed in future cultivars. It is necessary to recombine numerous parents to initiate the next generation.

Cumulative resistance may be achieved by combining components of resistance and by combining genes for particular component of resistance. Such an accumulation of resistance factors makes much more difficult natural selection of biotypes able to infest or injure the resistant variety (21).

Initial screening based on seedling mortality is especially valuable because it measures the sum of the three resistance categories. Greenhouses and environmentally controlled growth chambers make it possible to maintain environmental conditions for specific selection over extended periods. Seedling resistance thus obtained must subsequently be evaluated under field conditions.

Entomological Techniques and Procedures

Natural selection seldom occurs under intense cropping, since it does not assure evolution in favor of cultivars of desirable agronomic or esthetic values. For many insects, however, the outbreaks which occur periodically may be used to select plants showing varying degrees of resistance. These outbreaks have been particularly useful in selecting plants with resistance to the pea aphid and to the spotted alfalfa aphid; also for recurrent selection to develop resistance to the potato leafhopper and to the alfalfa weevil. Areas where infestation and damage are most frequent are valuable for resistance-evaluation nurseries.

Thousands of seedlings can be evaluated rapidly under controlled conditions in greenhouses and growth chambers. Mass rearing is required to attain appropriate infestation levels.

Mass screening of seedlings is valuable because resistant individuals often are a small minority of a generally susceptible population. Environmental conditions must be adjusted to favor either the plants or insects according to the selection pressure required, in addition to maintaining the appropriate infestation level and homogenous distribution of the insects.

Diets of known composition for phytophagous insects offer several obvious advantages. When insect cultures are

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known and nutrition is reproducible, one can conduct various tests and large-scale screening for resistance. Nutrition and metabolism can be studied by varying chemical and physical characteristics of diets and environmental conditions.

Insects that feed on stored products and omnivorous species are comparatively easy to adapt to laboratory culture. Insects that feed on growing plants are more selective; some choose a single species as their host or feed on a specific tissue or plant organ.

Resistance is usually measured by counting, weighing, or estimating volume of the surviving insect population or estimating damage to plants. Various indirect methods may be used to determine the surviving insect population: skins shed, parasite exit holes, and parasitized insects. Egg counts may suggest nonpreference. Examples of evaluation of plant damage are height, number of leaves, chlorotic spots, area of leaves consumed and borer holes. Most researchers score damage on a 1 (least) to 9 (most) scale.

Inheritance of Resistance to Insects

Identifying diverse sources of resistance broadens the genetic base of resistance and makes it possible to develop isogenic lines which are valuable tools for studying the mechanisms of resistance.

Although remarkable progress has been made in the development and release of insect-resistant germ plasm and cultivars, genetic makeup and mode of inheritance only rarely have been thoroughly analyzed. The usual procedure is to test the F_2- and F_3- segregates and backcross progenies; sometimes diallel crosses are also used when several resistant or susceptible varieties are available. More advanced techniques were used in breeding for resistance to European corn borer, such as test crosses involving marker genes and reciprocal translocations to determine the chromosomes or their arms that bear resistance genes. The mutable system Ac-Ds was applied to study the potential of genes to induce mutations conveying resistance to the corn borer and mutations conveying resistance to stalk rot disease in otherwise susceptible lines (9).

Resistance to the Hessian fly has been the most thoroughly analyzed to determine the different genes involved and what each contributed (8). Five pairs of dominant and partially dominant genes and possibly five additional recessive factors are being used in breeding for fly resistance.

Resistance to the cereal leaf beetle ("Oulema melanopus" L.) in wheat is a function of pubescence on the leaves. Analyses of data on F_1, F_2, and backcross progenies from crosses between glabrous and pubescent wheat varieties have shown pubescence to be quantitatively inherited (25).

Inheritance of resistance to first brood European corn borer in corn inbred lines was reported (23) as three pairs of genes with partial phenotypic dominance of susceptibility in the cross M 14 (S) x MS 1 (R). One or two pairs were responsible in the cross B 14 (S) x N 32 (R), and a single dominant gene, in WF 9 (S) x gl 7 V 17 (R). Most genetic variance is additive although a portion is dominant (26). Inheritance of resistance to the second brood is still unknown although data from 45 diallel crosses among 10 inbred lines indicate that resistance is transmitted in hybrid combinations (9, 19).

Potato leafhopper resistance in alfalfa is correlated with pubescence but there is evidence of heritable resistance also in glabrous plants. Resistance appeared dominant to susceptibility to leaf-hopper yellowing, but number of genes involved could not be determined.

Hostplant Resistance in Pest Management

Hostplant resistance was historically established in areas and crops where this was the only possible specific plant protection. "Grape Phylloxera" in Europe in the 1870's is an example. Resistant varieties in wheat against Hessian fly or wheat stem sawfly, "Cephus cinctus," are later examples. In other crops, resistance only recently has become either a supplement or a substitute for other pest control methods. Resistant varieties may improve the effectiveness of insecticides and make it possible to omit or reduce treatments, and thus escape or lessen undesirable residues or side effects.

Continuous use of relatively large amounts of pesticides over large cotton acreages has left residues at levels sometimes phytotoxic to the crop. These residues are carried to other areas, streams, and lakes. This results in a vicious cycle: The insect pests become increasingly harder to kill. Eventually there is a resurgence of the target pests and outbreaks of secondary pests. In an effort to interrupt this treadmill, major funds are being directed by various agencies and foundations toward cotton including development of resistant varieties.

An important goal in each pest management program is to establish economic injury levels for local areas and conditions. Acceptable injury is sometimes high, particularly when the crop is vigorously developing. Breeders should maintain or achieve high tolerance in newly developed cultivars. Highly tolerant varieties may be regarded as defensive strategy against the development of new, more aggressive biotypes. The insect population may reach densities high enough to allow outbreeding of the population, avoiding new biotypes, without economic injury. On the other hand, varieties bred for antibiosis or nonpreference-type of resistance when they monopolize much of the acreage create selection pressure which screens the population for the most aggressive biotypes.

The significance of hostplant tolerance in pest management is that it allows the hostplant to support subeconomic levels of the pest species while supporting the pest's natural enemies. Low densities of the pest species may be pivotal reserve food supply for beneficial organisms needed later in the growth period in the same or neighboring crops. The higher the economic injury level a variety has, the more numerous are insects it can tolerate and the longer it can wait for natural enemies to be effective.

Neighboring crops, too, may benefit. Varieties of alfalfa tolerant of pea aphids attract and maintain high populations of ladybeetles and syrphid fly larvae, which peak early and then move on to protect nearby crops. Also after each alfalfa cutting, predators and parasites are forced to forage in neighboring crops, for example, sorghum infested with greenbugs.

Farmers should be educated to accept some damage to tolerant varieties during an outbreak. The damage is still much less than on a susceptible variety. Producers of fruit and vegetables with an economic injury threshold near zero may have to resort to specific insecticides, but in reduced amounts.

In varieties of squash, the percentage of infested fruits decreases as the degree of resistance to pickle-worm increases. This is ture in both treated and untreated plots, but treatment is advantageous (4) only for susceptible and moderately resistant varieties.

Even low to moderate resistance may allow treatments to be omitted or to be initiated later or stopped earlier in the season, thus protecting natural enemies and reducing residues on fruits and in the soil.

Another example of beneficial effect of moderate resistance was shown by comparing moderately tolerant alfalfa varieties Team and Weevlchek with Cherokee, which is susceptible to alfalfa weevil (table 2). The moderately tolerant varieties made it possible to delay spraying and to omit one treatment (table 3).

Advantages to producing several moderately resistant varieties instead of one highly resistant one include: (1) moderately resistant germ plasma occurs more frequently than near-immunity in widely diverse germ plasm; (2) greater diversity in the gene pool allows one to adapt new varieties to local agronomic or ecologic conditions; (3) varieties may be changed more frequently; and (4) monoculture and monopoly of one single variety, which a new, aggressive biotype might destroy, can be avoided.

Value of Hostplant Resistance

It is difficult to estimate the value of insect-resistant cultivars because insects damage susceptible crops in many ways and the extent of damage varies widely. Losses from the "grape Phylloxera" in France in 1888 were estimated at 10 billion francs ($2 billion).

Painter estimated that resistant Pawnee wheat yielded about 14 bushels per acre more under heavy Hessian fly attack than susceptible Tenmarq. Gallun's (8) survey indicated that the United States grew 8½ million acres of wheat resistant to the Hessian fly in 1969. One cannot assume a 14-bushel-per-acre increase for all those acres, however, because not all the acreage would have been heavily infested.

Luginbill (19) estimated that using resistant spring wheat, Rescue, on Montana's sawfly-infested acreage in 1948 reduced damage approximately $4 million. After that, sawfly populations and wheat losses were reduced to a minimum in all areas where Rescue was grown. The 1 bushel of seed obtained in 1944 from Canada saved Montana farmers at least $40 million in 10 years. Savings to Canadian farmers were many times more.

The contribution of resistance to European corn borer control is difficult to assess because seed companies do not disclose the pedigree of commercial hybrids and the number of resistant inbred lines involved. In 1949, when all known control practices (including chlorinated hydrocarbon insecticides) were in effect, but resistant hybrids were not generally used, loss due to the European corn borer was $350 million. In the 1960's when resistant hybrids were used on 30 million acres, annual losses averaged about $10 million.

Dicke (24) reported that hybrids resistant to corn borer reduced the loss at least 20 bushels per acre when borer infestation was heavy. A fourth of that loss on the 30 million acres of resistant corn grown in 1962 would be $150 million in savings. In addition to reducing crop loss, growing resistant corn effectively reduced or suppressed borer populations 50 to 60 percent, thus reducing losses of subsequent crops.

The corn earworm causes an estimated annual loss to sweet corn growers in the United States of more than $12 million even when insecticides are applied. The estimated cost of chemical sprays and the value of corn forage lost by

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contamination with chemical residues brings total estimated savings from resistant hybrids to more than $17 million annually. Damage to dent corn in the United States has been estimated at $170 million a year. Much of that loss could be prevented by developing and growing resistant hybrids (19).

Luginbill (19) gave $35 million as a conservative estimate of annual savings to growers using spotted alfalfa aphid-resistant alfalfa cultivars. Resistance helps establish and maintain stands, assures both higher quality and yield of forage, and lower insect and disease control costs. Resistant cultivars became well established while susceptible entries were killed (28, 29, 53, 54). Infestations that killed mature stands of susceptible entries did not kill resistant entries. Where the spotted alfalfa aphid occurred after the last cutting, winter survival paralleled resistance scores recorded the previous fall (5). Where pea aphids damaged susceptible cultivars, resistant entries produced two to three times more forage (22, 30). Average percentage increases in forage yields for resistant over susceptible plants were 211, 188, 107, and 114 percent for the first, second, third and fourth cuts, respectively. These resistant selections maintained a 78 percent increase over susceptible plants in the first cutting the following year (13). Under epidemic infestations of spotted alfalfa aphids, resistant cultivars yielded three to four times more than susceptible ones. In 15- to 80-acre fields foliage damage by the spotted alfalfa aphid was 15 to 22 times greater on susceptible than on resistant cultivars (1).

Effect of Resistance on Feeding Value

Apprehension has been expressed regarding potentially harmful side effects of insect-resistant varieties on the nutritive value of feed. Tolerance is less suspect than antibiosis or nonpreference. However, reactions of man or domesticated animals should not be directly inferred from the effects of resistant varieties on insects.

Hostplant resistance in annual crops lasts a relatively short time. Chemical substances causing resistance are biodegradable, selective agents directed mostly towards mechanical and physiological injuries. Resistance is sometimes localized in some tissues or plant organs and absent in others. Sometimes the chemicals are biologically active only for a short time at certain developmental stages.

Protein, carotene, and digestible dry matter were similar in susceptible alfalfa varieties and those resistant to the pea aphid and spotted alfalfa aphid (15, 17, 36). Likewise, chemical components of resistant "Team" alfalfa were similar to those in susceptible varieties. Neither digestibility coefficients nor performance of yearling Holsteins differed significantly when fed resistant or susceptible varieties (2).

Quality and nutritive value as feed is improved by hostplant resistance because less protein, carotene, and vitamin A are lost from resistant than from susceptible varieties. Protein yields of resistant Kanza under attack by the pea aphid were almost double, and carotene yields triple those of the susceptible cultivars, Buffalo, Ranger, and Vernal (31). On the other hand, Loper (18) reported higher coumestrol content in aphid-susceptible Vernal than in resistant Moapa and Washoe cultivars when all were subjected to aphids.

Price of Hostplant Resistance

Successful development of hostplant resistance to supplant and supplement chemical control requires continuous, vigorous long-range programs, the benefits of which may not be reaped for 10 or more years. Relatively modest budgets have demonstrated successful hostplant resistance. Cost of developing Moapa alfalfa resistant to the spotted alfalfa aphid was reported as less than $30,000 (10).

Luginbill (19) estimated the total cost of research by Federal, State, and private agencies on resistance to four insect pests at $9.3 million. The professional man-years required were 115 for the Hessian fly, 92 for the sawfly, 119 for the alfalfa aphid, and 136 for the European corn borer. Savings to farmers, which pass to consumers in lower food prices, are estimated at $308 million a year. Assuming that a variety or inbred line will be grown successfully for about 10 years, the annual return for each dollar invested in research and development of hostplant resistance was $300. This does not include the bonus that is likely from effects on subsequent crops of eradicating or suppressing insect pests, or savings from eliminating chemicals and their residues.

Increased funds will be needed for future programs to screen for resistance to diseases, insects, and nematodes among such diverse crops as cereals, forage legumes, fiber crops, tropical food crops, shade trees, vegetables and others. Needed for the job are major investments for modern greenhouses and growth chambers and funds to maintain them. To meet the increased demand for basic information on the mechanism of resistance, such expensive equipment as scanning electron microscopes, gas chromatographs, spectrophotometers, instruments for radioactive tracer technique, and computers must be made available. Desirable instrumentation should be expanded as hostplant resistance is recognized as an ideal area for interdisciplinary research.

Traditionally, hostplant resistance has been attempted only against one insect species at a time. Stepped-up screening procedures should be able to screen for multiple resistance simultaneously in several crops against many insect pests, diseases, and nematodes.

Although resistance breeding requires a long-range program and teams of well-trained workers and technicians, it does not necessarily follow that breeding for resistance is less flexible than developing chemical controls, or that it cannot easily adjust to suddenly changing situations caused by newly imported pests. The Hessian fly, the European corn borer, the cereal leaf beetle and the spotted alfalfa aphid are all imported pests to which resistant varieties have been successfully produced in reasonably short time.

For a long time, all inputs in hostplant resistance came from Federal, State, and a few private organizations. The public agencies met barriers against long-term studies and development programs. Our "publish or perish" evaluation system also favors short-term projects that give "salami-sliced" publications in rapid succession. A further handicap is the lack of properly trained technicians because graduate students cannot remain on long-term projects. Technicians could do the tedious routine work of screening literally thousands of entries in fields, greenhouses, and growth chambers. A well-trained technical staff also would take better care of such expensive items as growth chambers and continuous mass rearing of insects, with fewer personnel turnovers and interruptions for on-the-job training.

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Control of the Hairy Chinch Bug in Turfgrass in the Northeast with DURSBAN Insecticide

By Herbert T. Streu and Carlos Cruz,
Department of Entomology and Economic Zoology,
Rutgers University — The State University
New Brunswick, N.J.

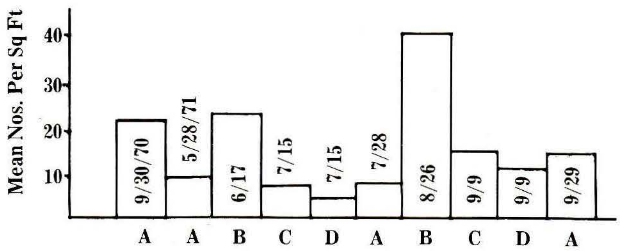

Figure 2—Peak populations of various instars of hairy chinch bugs as mean numbers counted per square foot in a New Jersey turfgrass in 1971. A=adults, B=first and second instars, C=third instar, D=fourth and fifth instars. Adults of the 1970 second generation (9/30/70) overwinter to the following spring (5/28/71). The first generation extends from June (6/17/71) through July (7/28). The second generation extends from August (8/26) through September (9/29). These second generation adults are, in turn, the overwintering insects which lay the eggs for the first generation of the following season.

EDITOR'S NOTE: DURSBAN® Insecticides are currently registered for control of chinch bugs, sod webworms (lawn moths), cutworms, earwigs and grasshoppers infesting home lawns and other ornamental and recreational turf grass areas.

Research data indicate that these products are also effective for the control of ants, brown dog ticks, crickets, fleas, sowbugs, turfgrass weevil and white grubs infesting turf as well as for control of a wide range of arthropod pests infesting ornamental plants. Data have been submitted in support of registration of label claims for control of these pests.

INTRODUCTION

The hairy chinch bug "Blissus leucopterus hirtus" Montandon is one of the major insect pests attacking turfgrasses in the Northeast. It feeds on and damages most of the common turfgrasses, including ryegrasses, bluegrasses, red fescues, and bentgrasses. The bug prefers hot, dry areas, is gregarious and tends to congregate. As a result, feeding damage is usually first observed as a number of dry brown spots in well-drained sunny locations (Fig. 1). In the Northeast the red fescues are particularly susceptible to damage and may be killed in hot dry seasons.

The hairy chinch bug overwinters as an adult. In New Jersey, there are two generations per summer season (Fig. 2). The second generation is the largest and produces the overwintering adults. The following spring, these adults become active and the females lay the eggs which give rise to the first summer generation. Adults develop within four to five weeks, and produce the eggs of the second generation.

In the past, chlordane was widely recommended and used for chinch bug control until control failures became common and widespread. Recently, the organophosphate materials, such as diazinon, ethion and ASPON insecticide have been used as well as the carbamate insecticides, such as carbaryl and BAYGON insecticide. Interest in new compounds, however, has been stimulated by persistent reports of control failures and phosphate-resistance in the South (Kerr 1965, Stringfellow 1969) as well as the failure of most compounds to give season-long residual control in the Northeast. One of the objectives of research being conducted at Rutgers is to evaluate the effectiveness of several new and promising insecticides for usefulness in turfgrasses, and particularly for control of chinch bugs in New Jersey. The results of some of that work are presented here.

MATERIALS AND METHODS

Evaluations of insecticidal activity were made in turfgrasses consisting of mixtures of common Kentucky bluegrass and red fescue, and in a turf of FYLKING Kentucky bluegrass and PENNLAWN red fescue. Plots were 100 square feet in area (10 ft x 10 ft) and treatments were replicated three times and randomized in a complete block design. Insecticides, formulated as emulsifiable concentrates, were applied as drenches in 4 gals. of water per plot (approximately 1700 gallons per acre). Insecticides, formulations and rates of application were as follows:

Material	Formulation	Application Rate (lb. a.i./acre
Chlordane	8 lb/gal	8 lb
Diazinon AG500	4 lb/gal	8 lb
DURSBAN M	4 lb/gal	1 lb
PHOSVEL	3 lb/gal	1 lb

Chlordane and diazinon were applied twice, once in mid-June, and once in mid-July. Following application, the entire area was irrigated with about ½ in. of water to facilitate insecticide penetration into the thatch. DURSBAN® M insecticide and PHOSVEL insecticide were applied once, and the treatment areas irrigated as above.

Insecticide activity was evaluated by estimating the number of live chinch bugs per square foot, using a heavy-gauge metal flotation cylinder, open at both ends. The cylinder was driven into the ground, filled with water, and the number of live bugs which floated to the surface in 10 minutes was counted. Three counts were made per replicate.

Arthropods and other organisms were extracted from four soil and thatch cores, each 2 in. in diameter and 2 in.

deep, which were removed from each plot and placed in a Berlese funnel device similar to that described by MacFadyen (1961). The cores were placed thatch side down over funnels opening into bottles of saturated solutions of picric acid. A temperature-humidity gradient was maintained by heating the tops of the cores to 35 degrees C and cooling the bottoms (thatch-sides) to 15 degrees C and adding water mist to maintain about 90-100% RH. The cores remained in the extractor for 10 days.

RESULTS AND DISCUSSION

No injury or other change in appearance of the grasses was observed in any of the treatments. During the experiments, the area had been maintained in good growing condition with applications of water and fertilizer.

Data show that of those tested, DURSBAN insecticide was the most effective in controlling chinch bugs, even though it had been applied only once and at only one pound active ingredient per acre rate.

Counts made in the Kentucky bluegrass-red fescue area show that DURSBAN insecticide was effective in controlling a population for the entire season. Similar results were recorded in the combination of FYLKING and PENNLAWN turf, with chinch bugs being found in only one corner of one of the 3 plots treated with DURSBAN. Of even greater interest, however, are the counts made in the Kentucky bluegrass-red fescue turf the following June (Table 1) which indicate that DURSBAN insecticide exerted a surprisingly long control effect in an area of relatively high chinch bug populations. The low numbers counted on June 25, almost one year following treatment were undoubtedly due to the effectiveness of DURSBAN in controlling the chinch bug for the entire season and thereby reducing the number of overwintering insects. Analysis of the data allowed highly significant differences ($p<0.01$) between all treatments with DURSBAN and the untreated plots.

Diazinon did not give satisfactory control for more than one month following the second application and chinch bug populations in chlordane-treated areas were always higher than in untreated plots. These differences have been found consistently over several years (Streu and Vasvary 1966, Streu 1969) and interference with some as yet unknown natural population regulating mechanism has been suggested.

A number of chinch bug predators have been isolated and identified from turf grass by the present authors and have been observed to be affected by chlordane. Insecticide failure to control chinch bugs may be interrelated with effects on natural control factors, including predators and parasites, as well as through selection of pest populations resistant to insecticides.

Observations during flotation counts plus counts of organisms extracted from soil and thatch samples showed that immediately after treatment DURSBAN insecticide removed most of the arthropods inhabiting turfgrass, including Collembola and other insects as well as predatory mites (primarily Mesostigmata) and insects. By the end of the season, however, the Collembola and mesostigmatid mite populations were greater in plots treated with DURSBAN than in untreated areas. In contrast, the total numbers of arthropods, including predatory mites and Collembola, counted in chlordane-treated areas were considerably less than in other plots.

More oribatid mites, however, were observed in areas treated with DURSBAN during flotation counts than in other treatments. Furthermore, more were extracted, particularly at the end of the season, from soil and thatch samples from plots treated with DURSBAN than from either chlordane or untreated areas. This group of mites is thought to be associated with decomposition of organic matter and may play an important role in the turnover of decaying thatch material.

The importance of the observations is a matter of conjecture at this time. Removal of predators and other organisms may have important effects if resistant populations appear, as indicated by the data from chlordane-treated areas where control failure has resulted in significantly larger populations of chinch bugs than in untreated areas.

CONCLUSION

DURSBAN insecticide effectively controls the hairy chinch bug for an entire season in New Jersey when applied once in the spring at the rate of 1 pound of active ingredient per acre. Residual effects are reflected in very low spring populations of over-wintering adults in comparison to other materials tested. Based upon the life history, treatment in mid-June is most effective, killing first and second instar nymphs of the first generation. DURSBAN insecticide should find general acceptance in

(Continued on Page 24)

FROM

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(Continued from Page 23)
the Northeast as a superior control for chinch bugs in commercial use as well as for the homeowner.

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University of Massachusetts Turfgrass Research Fund

A Research Directives Committee consisting of five golf course superintendents and two turf industry representatives has recently met to determine the course of research which involves Turf Research Funds. The committee will serve as a guiding unit to insure that research conducted at the University will be a relevant service to people in the field. To date, a total of $4500 has been contributed by alumni and golf clubs.

After considering the facilities and money available for the first year, the committee decided to concentrate research problems on fairway turf. A comprehensive outline of research will be submitted to the committee for approval during January.

A total of 29 Massachusetts golf courses and nearly 100 alumni have contributed to date. The scope of this project will largely be determined by the degree of participation of clubs and alumni. A satisfactory start has been made toward developing a worthwhile program at the University. In order to continue to improve and expand the research program, more agencies and individuals will have to lend their support. With cooperation from the field, a program that will reward everyone in the turf industry can be developed.